Japanese Laid-open Patent
Laid-open Number: Hei 11-26887
Laid-open Date: January 29, 1999
Application Number: Hei 9-197886
Filing Date: July 7, 1997
Applicant: Sumitomo Electric Industries, Ltd.

(54) [Title of the Invention] Semiconductor laser with a diamond heat dissipation part

(57) [Summary]
[Object] To provide a semiconductor laser that oscillates stably at high output power and that is provided with a heat sink made of diamond that is excellent in heat dissipation and exerts no thermal stress on a semiconductor laser chip.
[Construction] A vapor synthetic diamond layer with a thickness of 3 m to 9 m is formed on a plate-like base the surfaces of which then are coated with a metallized layer. A semiconductor laser chip is fixed thereonto with a brazing filler metal having a thickness of 2 m to 8 m.

[Scope of Claims]

[Claim 1] A semiconductor laser with a diamond heat dissipation part, comprising:
a plate-like base;
a vapor synthetic diamond layer with a thickness of 3 m to 9 m formed on a surface of the base;
a metallized layer provided to cover at least part of a surface of the diamond layer; and
a semiconductor laser chip fixed to the metallized layer formed on the diamond layer with a brazing filler metal having a thickness of 2 m to 8 m.

[Claim 2] The semiconductor laser with a diamond heat dissipation part according to claim 1, wherein the vapor synthetic diamond has a thermal conductivity of 500 W/m·K to 2000 W/m·K at a temperature between a room temperature and 400°C.

[Claim 3] The semiconductor laser with a diamond heat dissipation part according to claim 1 or 2, wherein the vapor synthetic diamond is diamond grown heteroepitaxially on the base.

[Claim 4] The semiconductor laser with a diamond heat dissipation part according to any one of claims 1 to 3, wherein surface roughness of the vapor synthetic diamond is decreased by polishing, so that Rmax is set to 50 nm and Ra to 20 nm or less.

[Claim 5] The semiconductor laser with a diamond heat dissipation part according to any one of claims 1 to 4, base

the substrate has a thickness of 100 m to 1000 m.

[Claim 6] The semiconductor laser with a diamond heat dissipation part according to any one of claims 1 to 5, wherein the base is made of one material selected from a group consisting of Si, SiC, AlN, Cu, a Cu-Mo alloy, a Cu-W alloy, and a Cu-Mo-W alloy.

[Claim 7] The semiconductor laser with a diamond heat dissipation part according to any one of claims 1 to 6, wherein the brazing filler metal is made of at least one material selected from a group consisting of Au, Ag, Ge, In, Pb, Si, and Sn.

[Claim 8] The semiconductor laser with a diamond heat dissipation part according to any one of claims 1 to 7, wherein the metallized layer is formed of at least one material selected from a group consisting of Au, Mo, Ni, Pd, Pt, and Ti.

[Detailed Description of the Invention]

[0001]

[Technical Field to which the Invention belongs]

The present invention relates to a semiconductor laser with a diamond heat dissipation part. Particularly, the present invention relates to a configuration of a semiconductor laser whose performance is improved through the relaxation of thermal stress produced between the semiconductor laser and the diamond heat dissipation part.

[0002]

[Prior Art]

With recent progress of an information communication society, the technology of mass information transmission such as multichannel transmission such as cable TV (CATV), long-distance backbone transmission and reception using submarine cables, and the like has been developed actively. A high output semiconductor laser is indispensable for such mass information transmission and the demand therefor is increasing year after year. In order to maintain stable oscillation of such a high output semiconductor laser, a high-performance heat dissipation part is required. The heat dissipation part is also called a "heat sink".

[0003]

Naturally, materials with high thermal conductivity are suitable for the heat dissipation part. Metallic materials are used for the heat sink. For instance, a metallic material with high thermal conductivity such as CuW or the like (Japanese Patent Application Laid-open No. Hei 1-187991, Japanese Patent Application Laid-open No. Hei 2-257689) is used. However, metal does not have very high thermal conductivity and therefore may not be sufficient to cool a semiconductor laser that generates heat intensively.

[0004]

The material having the highest thermal conductivity among all the materials is diamond. Since the diamond is expensive but is excellent in thermal conductivity, it has been brought into use a little as a heat dissipation part for a semiconductor laser.

[0005]

(1) Japanese Patent Application Laid-open No. Hei 5-13843 entitled "Heat Dissipation Part and Semiconductor Laser with the Same" proposes a semiconductor laser that is obtained through formation of diamond only on a stem and brazing of a semiconductor laser thereonto. The thickness of the diamond film is set to 10 m to 500 m. It is described that the diamond film must have a thickness of at least 10 m since the thickness of the diamond affects the heat dissipation performance. However, there is no description as to the thickness of the brazing filler metal. The problem caused by the difference in coefficient of thermal expansion between a semiconductor laser and a diamond heat sink has not been noticed.

[0006]

(2) Japanese Patent Application Laid-open No. Hei 8-195367 entitled "Wafer and Method of Manufacturing the Same" proposes a large diameter wafer provided with diamond including a diamond film formed on a substrate made of Si or the like. This wafer is warped to be higher in the middle. It is not described that this is a heat sink for a semiconductor laser. In addition, there is no mention of the difference in coefficient of thermal expansion between the semiconductor laser and the wafer.

[0007]

(3) Japanese Patent Application Laid-open No. Sho 48-79338 entitled "Heat Dissipation Electrode and Method of Manufacturing the Same" describes that diamond itself is used as a heat sink and an electrical conduction property is provided through coating of natural diamond with chromium, platinum, and gold. The object to be cooled is an impatt diode or a Gunn diode and is not a semiconductor laser.

[0008]

(4) Japanese Patent Application Laid-open No. Sho 49-99482 entitled "Method of Assembling Subminiature Semiconductor Electronic Equipment" describes that a natural diamond sphere that has a substantially spherical shape and a small flat surface at its upper part is metallized and a Gunn diode is mounted thereon. It is described that since the diamond has a spherical shape, it is excellent in coolability as compared to that of diamond with a rectangular parallelepiped shape. However, this is not a cooling

mechanism for a semiconductor laser.

[0009]

(5) Japanese Patent Application Laid-open No. Sho 50-67582 entitled "Method of Manufacturing Semiconductor Element" describes that a hole is made in a Cu block, a natural diamond block is embedded therein, and a semiconductor device that generates heat considerably such as an impatt diode or the like is fixed thereonto. No thin vapor synthetic diamond film is used. Cracks caused by the difference in coefficient of thermal expansion between the diamond and the element and the like are not considered as problems.

[0010]

(6) Japanese Utility Model Application Laid-open No. Sho 53-118470 entitled "Semiconductor Device" describes that a diamond-like carbon film is formed on a Cu substrate, which is gold-plated, and then a light emitting diode is fixed thereonto. It is described that by this manner, a chip is insulated by the carbon film. The diode is attached to the gold layer and is not brazed to a diamond film.

[0011]

(7) Japanese Patent Application Laid-open No. Sho 63-41055 entitled "Heat Dissipation Configuration of Semiconductor Device" describes that a diamond film with a thickness of 10 m is formed on a Si substrate, a gold film further is formed, and a chip is attached thereto with the gold used as a solder.

[0012]

(8) Japanese Patent Application Laid-open No. Hei 2-26057 entitled "Heat Sink" proposes a heat sink including a diamond film having a thickness of 50 m formed on a substrate containing metal oxides (Al_2O_3, TiO_2, and SiO_2) dispersed in a Cu alloy or Cu. The heat sink is used for an IC package, a hybrid IC, or the like. There is no description as to the configuration in which such an IC package, a hybrid IC, or the like is attached to the heat sink.

[0013]

(9) Japanese Utility Model Application Laid-open No. Hei 3-6862 entitled "Heat Dissipation Substrate" proposes a substrate with a diamond film formed on the surface of a heat dissipation substrate by patterning synthesis.

[0014]

[Problems to be solved by the Invention]

In a semiconductor laser having a diamond heat sink, the semiconductor laser element and diamond are joined together with a brazing filler metal. For the brazing, operations are required that include increasing the temperatures of the diamond and the semiconductor laser to a temperature at which the brazing filler metal melts to braze them to each other and

then lowering their temperatures to room temperature. With this temperature rise and fall, there arises a problem of thermal stress.

[0015]

The coefficient of thermal expansion of InP or GaAs as a typical material of a semiconductor laser element is twice to three times the coefficient of thermal expansion of diamond. Since their coefficients of thermal expansion are considerably different from each other, great thermal stress is produced in the semiconductor laser element while their temperatures decrease from the brazing temperature to room temperature. When this thermal stress is great, the semiconductor laser element is cracked. Even when no crack is caused, there arise various problems such as decrease in laser oscillation intensity, shortening of laser lifetime, and the like. The diamond used for a heat dissipation part for a conventional semiconductor laser usually has a thickness of at least 200 m. When such thick diamond is used for a heat dissipation part, great thermal stress is caused between a semiconductor laser and the diamond and thereby various problems as described above are caused by the thermal stress.

[0016]

The request for the reduction in price of a semiconductor substrate such as a heat dissipation part is coming to be harsh. Diamond with high thermal conductivity is excellent in heat dissipation but is very expensive. In order to achieve cost reduction while using an expensive material, it is necessary to reduce the thickness of diamond to be a necessity minimum. A diamond film is formed on a substrate by a vapor synthetic method and then is obtained as an independent film through the removal of the substrate. When the diamond layer is excessively thin, diamond is cracked during the removal of the substrate. In an extreme case, there arise problems such as split of the diamond and the like.

[0017]

In order to prevent the diamond from being cracked when the diamond film is separated from the substrate to be the independent film, the diamond film must have a thickness of at least 200 m. In other words, it was necessary to synthesize diamond with a thickness of at least 200 m on a substrate. It is not easy to reduce the price of the heat dissipation part formed using such a diamond independent film.

[0018]

The present invention is intended to solve the problems as described above. An object of the present invention is to provide a semiconductor laser that allows the cost for manufacturing a diamond heat dissipation part to be reduced and prevents its performance from being deteriorated due to

thermal stress through the use of a vapor synthetic diamond with a thickness of necessity minimum synthesized on a substrate as a heat dissipation part with the vapor synthetic diamond attached to the substrate and the optimization of the thickness of a brazing filler metal provided between a semiconductor laser element and the heat dissipation part.

[0019]

[Means for solving the Problem]

A semiconductor laser according to the present invention is characterized by including a heat dissipation part formed of a vapor synthetic diamond film with a thickness of 3 m to 9 m formed on a plate-like substrate and a semiconductor laser element that are joined together with a brazing filler metal whose thickness is 2 m to 8 m.

[0020]

[Embodiment Mode of the Invention]

A semiconductor laser element and a vapor synthetic diamond with a thickness of 3 m to 9 m formed on a plate-like base are joined together with a brazing filler metal having a thickness of 2 m to 8 m, so that the thermal stress produced in the semiconductor laser element can be reduced. It has been considered that a conventional diamond heat sink with a thickness below 200 m is unsuitable. However, the present invention does not require such a thickness and maintains that an ultrathin diamond heat sink may be employed.

[0021]

Since the maximum thickness is 9 m, the production cost can be reduced considerably as compared to the case using conventional diamond with a thickness of at least 200 m. The present invention not only allows the production cost to be reduced simply but also prevents the semiconductor laser chip from being deteriorated due to the thermal stress while allowing the thickness of the diamond film to be reduced. The aforementioned conventional technique (1) proposes a heat sink in which diamond has a thickness of 10 m to 500 m. However, such a heat sink is excessively thick and therefore may cause cracks in the chip to hinder laser oscillation and deteriorate its characteristics.

[0022]

The diamond layer used in the present invention is produced on a base by a vapor synthetic method. Known methods of manufacturing vapor synthetic diamond can be employed including a combustion flame method, a thermal filament CVD method, a microwave plasma CVD method, and the like. The diamond synthesized on the base by the vapor synthetic method has an euhedral surface that is inherent in diamond and considerably high surface roughness. Hence, it is often not suitable for mounting of a semiconductor element unless it is

further processed. When the surface is rough, the semiconductor element cannot be brazed suitably and thereby the increase in thermal resistance is caused. Preferably, as the surface roughness, R_{max} is 50 nm or less and Ra is 20 nm or less. This can be achieved through surface polishing with a diamond wheel or the like. The surface roughness tends to increase with the increase in thickness of the diamond synthetic film. In the thin diamond film with a thickness of 3 to 9 m of the present invention, however, the above-mentioned surface roughness may be achieved without any particular processing to be carried out after the synthesis. In such a case, the surface polishing may be omitted. Usually, diamond formed on a base made of Si or the like described later by vapor synthesis is a polycrystalline substance. On the other hand, diamond grown heteroepitaxially on a base (single crystal) is a single crystal and it therefore is of very high quality and has high thermal conductivity. Hence, it is further preferable as the diamond layer used in the present invention. With respect to the thickness of the base used in the present invention, when it is excessively thick, the thermal resistance of the base increases excessively, and thus an excessively thick base is not preferable. On the other hand, however, an excessively thin film tends to cause defects such as cracks or the like and thus is not preferable in terms of mechanical strength. It is preferable to use a base with a thickness of 100 m or more and 1 mm or less. Conditions of the material of the base include the following: to be stable under the conditions for vapor synthesis of diamond, to allow diamond to be synthesized, to have not excessively low thermal conductivity, and to have a coefficient of thermal expansion that is similar to or higher than that of the semiconductor element to be mounted. Specifically, preferable materials include Si, SiC, AlN, Cu, a Cu-Mo alloy, a Cu-W alloy, a Cu-Mo-W alloy, and the like. Preferably, the brazing filler metal for joining the diamond surface and the semiconductor element together is made of at least one material selected from the group consisting of Au, Ag, Ge, In, Pb, Si, and Sn. In addition, it is preferable that the metallized layer on the diamond surface contains at least one selected from the group consisting of Au, Mo, Ni, Pd, Pt, and Ti.

[0023]

[Examples]

[Example 1 (Thermal Filament CVD Method)]

Diamond films with thicknesses of 3 m and 9 m each were synthesized through injection of hydrogen gas and methane gas onto a heated 3-inch Si substrate by the thermal filament CVD method. The conditions are as follows.

Substrate: Si Wafer 76 Ø × 0.5 mm
Filament Temperature: 2100°C
Substrate Temperature: 850°C
Hydrogen Flow Rate: 400 sccm
Methane Flow Rate: 5 sccm
Gas Pressure: 80 Torr
Synthesis Time and Film Thickness:
3 hours - 3 m (after polishing)
8 hours - 9 m (after polishing)

[0024]

These diamond films each had a thermal conductivity of 1000 W/m·K and a surface roughness after polishing of R_{max} = 40 nm and R_a = 10 nm. Each diamond film attached to the substrate was processed as follows without being separated from the Si substrate. The Si substrate coated with the diamond was cut into a 0.75 mm × 0.75 mm square shape with a YAG laser. The whole surfaces (the upper face, the lower face, and the side faces) were metallized with Ti, Pt, and Au. This is carried out for allowing brazing. A semiconductor laser chip formed of In-Ga-As-P with a dimension of 0.3 mm × 0.3 mm × 0.1 mm was brazed to the substrate coated with the diamond, which had been metallized, at a temperature of 290°C using a Au-Sn alloy brazing filler metal. In order to find out the optimum condition, the thickness of the brazing filler metal was changed variously.

[0025]

Thus, semiconductor lasers each having a heat sink were produced. There are two problems. One is heat dissipation performance. The other is thermal stress produced between the element and the heat sink. Insufficient heat dissipation results in unstable laser oscillation. Great thermal stress causes distortion in the semiconductor laser and may break the element. The thermal stress is required to be small and heat dissipation to be sufficiently high.

[0026]

Hence, with the brazing filler metals having various thicknesses, laser elements each of which was attached to a heat sink having a 3- m thick diamond film and lasers each of which was attached to a heat sink having a 9- m thick diamond film were allowed to oscillate continuously at an output power of 150 mW and thereby temperature variation and thermal stress in the semiconductor lasers were measured. Since the output is the same, the generated heat amount is also the same. Besides heat radiation, the heat is dissipated by thermal conduction through the chip, the brazing filler metal, and the heat sink. Table 1 shows measurement results in the case of the heat sink (diamond/Si substrate) having a 3- m thick diamond film.

[0027]
[Table 1]

Thermal stress and oscillation performance of lasers each of which was brazed to a heat sink including a 3- m thick diamond film and a Si substrate coated therewith and was allowed to oscillate continuously at an output power of 150 mW.

Sample No.	1	2	3	4	5
Substrate	Si	Si	Si	Si	Si
Diamond Thickness (m)	3	3	3	3	3
Brazing Filler Metal Thickness (m)	1	3	5	7	9
Thermal Stress (MPa)	95	45	30	20	10
Laser Oscillation Performance	Stable Oscillation	Stable Oscillation	Stable Oscillation	Stable Oscillation	Unstable Oscillation

[0028]

Sample 1 has the thinnest (1 m) brazing filler metal but greatest thermal stress, namely 95 MPa. The thin brazing filler metal allows excellent thermal conduction to be obtained between the chip and the heat sink. Hence, the heat of the chip is dissipated well and thereby the temperature increase can be suppressed effectively. Since the temperature is low, the laser oscillation is stable. Sample 2 includes a 3- m thick brazing filler metal that is thicker than that of Sample 1. Since the brazing filler metal has a stress relaxation effect, the thermal stress of the chip is reduced. On the other hand, however, the thermal conductivity decreases and thereby the temperature of the element increases.

[0029]

Samples 3 to 5 have brazing filler metals whose thickness increases in order of sample number. The stress exerted on the chip is reduced with the increase in thickness of the brazing filler metal. The thermal conductivity deteriorates in order of sample number and thereby the laser temperature increases by degrees in that order. In Sample 4, the brazing filler metal has a thickness of 7 m. The thermal stress is reduced to 20 MPa. The oscillation is stable in all Samples 1 to 4.

[0030]

In Sample 5, since the brazing filler metal has a thickness of 9 mm, the thermal stress is reduced to 10 MPa. It appears good but it is not. The laser temperature increases to 58°C instead. Since the laser temperature is high, the oscillation intensity decreases. When the driving current was increased such that constant intensity was obtained, the temperature further increased and thereby the

laser oscillation became unstable. This is because the brazing filler metal is excessively thick, which results in poor thermal conduction and in turn incomplete heat dissipation. Table 2 shows measurement results in the case of the heat sink (diamond/Si substrate) having a diamond film with a thickness of 9 m.

[0031]

[Table 2]

Thermal stress and oscillation performance of lasers each of which was brazed to a heat sink including a 9- m thick diamond film on a Si substrate and was allowed to oscillate continuously at an output power of 150 mW.

Sample No.	6	7	8	9	10
Substrate	Si	Si	Si	Si	Si
Diamond Thickness (m)	9	9	9	9	9
Brazing Filler Metal Thickness (m)	1	3	5	7	9
Thermal Stress (MPa)	-	70	55	35	20
Laser Oscillation Performance	Element Damaged	Stable Oscillation	Stable Oscillation	Stable Oscillation	Stable Oscillation

[0032]

The brazing filler metal of Sample 6 is the thinnest (1 m). The diamond film has a thickness of 9 m, which is excessively thick. Hence, the thermal stress cannot be relieved by the brazing filler metal with a thickness of 1 m. Due to the strong thermal stress, the chip was damaged during the process of temperature decrease from the brazing temperature to room temperature. Hence, it was not possible to carry out the energizing test. In Sample 7, the thermal stress produced by the thick diamond film (9 m) is relieved by the brazing filler metal to be reduced to 70 MPa. Since the thickness of the diamond film is three times the thickness (3 m) of the diamond film in the aforementioned example, excellent thermal conduction is obtained. Hence, the temperature can be suppressed to be low and thus stable oscillation can be achieved.

[0033]

With respect to Samples 7 to 10, the thermal stress is reduced with the increase in thickness of the brazing filler

metal in order of sample number. This is because the stresses opposed to each other are cancelled out by the brazing filler metal with a small Young's modulus. However, the thermal conductivity decreases due to the brazing filler metal instead and thereby the laser temperature increases. In Sample 10, the thermal stress is 20 MPa. Nevertheless, the oscillation is stable.

[0034]

[Comparative Example 1]

In the present invention, the thickness of the diamond film is an important factor. For comparison, the same experiment was carried out while the thickness was set to 100 m. A thick diamond film with a thickness of 100 m was synthesized through injection of hydrogen gas and methane gas onto a heated 2-inch Si substrate by the thermal filament CVD method. The conditions are as follows.

Substrate:	Si Wafer 50 Ø × 0.5 mm
Filament Temperature:	2100°C
Substrate Temperature:	850°C
Hydrogen Flow Rate:	400 sccm
Methane Flow Rate:	10 sccm
Gas Pressure:	80 Torr
Diamond Film Thickness:	100 m
Synthesis Time:	50 hours

[0035]

The above-mentioned conditions are substantially the same as those in conventional examples except that the methane flow rate is slightly different and the synthesis time is longer. While the diamond film was not separated from the Si substrate, the Si substrate coated with the diamond film was cut into a 0.75 mm × 0.75 mm square shape with a YAG laser. The whole surfaces (the upper face, the lower face, and the side faces) were metallized with Ti, Pt, and Au. A semiconductor laser chip formed of In-Ga-As-P with a dimension of 0.3 mm × 0.3 mm × 0.1 mm was brazed to the substrate coated with the diamond film, which had been metallized, at a temperature of 290°C using a Au-Sn alloy brazing filler metal. In order to make a comparison with Example 1, the thickness of the brazing filler metal was changed variously between 1 m to 9 m.

[0036]

With the brazing filler metals having thicknesses of 1 m to 9 m, laser elements each of which was attached to a heat sink having the 100- m thick diamond film were allowed to oscillate continuously at an output power of 150 mW and thereby temperature variation and thermal stress in the semiconductor laser were measured. The measurement results are shown in Table 3.

[0037]

[Table 3]

Thermal stress and oscillation performance of lasers each of which was brazed to a heat sink including a 100- m thick diamond film on a Si substrate and was allowed to oscillate continuously at an output power of 150 mW.

Sample No.	11	12	13	14	15
Substrate	Si	Si	Si	Si	Si
Diamond Thickness (m)	100	100	100	100	100
Brazing Filler Metal Thickness (m)	1	3	5	7	9
Thermal Stress (MPa)	-	-	-	-	-
Laser Oscillation Performance	Element Damaged	Element Damaged	Element Damaged	Element Damaged	Element Damaged

[0038]

Since the diamond film was thick, when the thicknesses of the brazing filler metals were in the range of 1 m to 9 m, the elements were cracked to be damaged during the temperature decrease from the brazing temperature (290°C) to room temperature. Hence, it was not possible to carry out the energizing test.

[0039]

[Example 2 (Microwave Plasma CVD Method)]

Diamond films with thicknesses of 3 m and 6 m each were synthesized through injection of hydrogen gas, methane gas, and oxygen gas onto a heated square SiC substrate whose one side was 20 mm by the microwave plasma CVD method. The conditions are as follows.

Substrate: SiC Plate 20 mm × 20 mm × 0.3 mm
Microwave Power: 3 kW
Substrate Temperature: 800°C
Hydrogen Flow Rate: 500 sccm
Methane Flow Rate: 15 sccm
Oxygen Flow Rate: 2 sccm
Gas Pressure: 90 Torr
Synthesis Time and Film Thickness: 3 hours - 3 m
6 hours - 6 m

[0040]

These diamond films each had a thermal conductivity of

1600 W/m·K. They have further excellent thermal conductivity as compared to that (1000 W/m·K) of the above-mentioned diamond films formed by the thermal filament method. Each diamond film was used as a heat sink without being separated from the SiC substrate. The SiC substrate coated with the diamond film was cut into a 0.75 mm × 0.75 mm square shape with a YAG laser. The whole surfaces (the upper face, the lower face, and the side faces) were metallized with Ti, Pt, and Au. A semiconductor laser chip formed of In-Ga-As-P with a dimension of 0.3 mm × 0.45 mm × 0.1 mm was brazed to the substrate coated with the diamond film, which had been metallized, at a temperature of 290°C using a Au-Sn alloy brazing filler metal. Such processes are the same as in the case of the Si substrate coated with the diamond film formed by the above-mentioned thermal filament method. As in the aforementioned examples, in order to find out the optimum condition, the thickness of the brazing filler metal was changed variously.

[0041]

As in the aforementioned examples, semiconductor lasers each having a heat sink were produced. With respect to them, thermal stress and element temperature of each laser chip were measured at constant optical power. In this example, since heat dissipation was excellent, the semiconductor laser power was set to 300 mW, which was twice the semiconductor laser power of the aforementioned examples (150 mW). Table 4 shows measurement results in the case of the heat sink (diamond/SiC substrate) having a diamond film with a thickness of 3 m.

[0042]

[Table 4]

Thermal stress and oscillation performance of lasers each of which was brazed to a heat sink including a 3- m thick diamond film synthesized on a SiC substrate by the microwave plasma CVD method and was allowed to oscillate continuously at an output power of 300 mW.

Sample No.	16	17	18	19	20
Substrate	SiC	SiC	SiC	SiC	SiC
Diamond Thickness (m)	3	3	3	3	3
Brazing Filler Metal Thickness (m)	1	2	4	6	8
Thermal Stress (MPa)	95	50	35	20	15

Laser Oscillation Performance	Stable Oscillation	Stable Oscillation	Stable Oscillation	Stable Oscillation	Stable Oscillation

[0043]

Sample 16 includes the thinnest brazing filler metal (1 m) and therefore the stress cannot be relieved. Thus, Sample 16 has a thermal stress of 95 MPa, which is the greatest thermal stress. The thin brazing filler metal is excellent in thermal conduction between the chip and the heat sink. Hence, the heat of the chip is dissipated well and thereby the temperature increase can be suppressed effectively. Since the temperature is low, the laser oscillation is stable.

[0044]

Samples 17 to 20 have brazing filler metals whose thickness increases in order of sample number. Since the brazing filler metal has a stress relaxation effect, the thermal stress in the chip is reduced with the increase in thickness of the brazing filler metal. On the other hand, however, the brazing filler metal hinders thermal conduction and thereby the temperature of the element increases. In Sample 20, the brazing filler metal has a thickness of 8 m. The thermal stress is reduced to 15 MPa and the element temperature increases. In each of Samples 16 to 20, the oscillation is stable. Table 5 shows the thermal stress measurement results in the case of the heat sink (diamond/SiC substrate) having a diamond film with a thickness of 6 m.

[0045]

Thermal stress and oscillation performance of lasers each of which was brazed to a heat sink including a 6- m thick diamond film formed on a SiC substrate by the microwave plasma CVD method and was allowed to oscillate continuously at an output power of 300 mW.

Sample No.	21	22	23	24	25
Substrate	SiC	SiC	SiC	SiC	SiC
Diamond Thickness (m)	6	6	6	6	6
Brazing Filler Metal Thickness (m)	1	2	4	6	9
Thermal Stress (MP)	-	65	50	30	15
Laser Oscillation Performance	Element Damaged	Stable Oscillation	Stable Oscillation	Stable Oscillation	Stable Oscillation

[0046]

Sample 21 includes the thinnest brazing filler metal (1 m). The diamond film has a thickness of 6 m, which is excessively thick. Hence, the thermal stress cannot be relieved by the 1- m thick brazing filler metal. Due to the strong thermal stress, the chip was cracked during the process of temperature decrease from the brazing temperature to room temperature. Hence, it was not possible to carry out the energizing test. In Sample 22, the thermal stress produced by the thick diamond film (6 m) is relieved by the brazing filler metal to be reduced to 65 MPa. Since the thickness of the diamond film is twice the thickness (3 m) of the diamond film in the above-mentioned example, excellent thermal conduction is obtained. Hence, the temperature can be suppressed to be low and thus the stable oscillation can be achieved.

[0047]

The thermal stress is reduced with the increase in thickness of the brazing filler metal from Sample 22 to Sample 25. Since the brazing filler metal allows the thermal conduction to decrease, the laser temperature increases. In Sample 25, however, the thermal stress is 15 MPa. In Samples 22 to 25, the oscillation is stable. Table 5 shows greater thermal stresses. Since the diamond is thicker, the stress produced between the diamond and the element increases.

[0048]

[Example 3 (Thermal Filament CVD Method + Plasma Jet CVD Method)]

Next, diamond nucleation on a single crystal Si substrate was carried out by the thermal filament CVD method and the substrate was coated with a diamond film by the plasma jet method. Thus, a diamond/Si heat sink was produced. A semiconductor laser chip was attached to the heat sink thus obtained and the same tests were carried out. (First Step: Nucleation) A nucleation process was carried out through injection of hydrogen gas and methane gas onto a heated 2-inch (100) single crystal Si substrate by the thermal filament CVD method. The conditions are as follows.

Substrate: (100) Single Crystal Si 50 Ø × 1 mm
Filament Temperature: 2000°C
Substrate Temperature: 700°C
Hydrogen Flow Rate: 400 sccm
Methane Flow Rate: 10 sccm
Gas Pressure: 30 Torr
Substrate Bias: -200 V
Nucleation Processing Time: 10 minutes

[0049]

(Second Step: Covering with Diamond Film)

The nucleated (100) single crystal Si substrate was coated with a diamond film with a thickness of 8 m by plasma jet CVD.

Substrate: Nucleated (100) Single Crystal Si
50 Ø × 1 mm
Substrate Temperature: 850°C
Hydrogen Flow Rate: 2 slm (= 2000 sccm)
Methane Flow Rate: 45 sccm
Argon Flow Rate: 5 slm (= 5000 sccm)
Gas Pressure: 5 Torr
Diamond Film Synthesis Time: 4 hours
Diamond Film Thickness: 8 m

[0050]

This diamond film had a thermal conductivity of 2000 W/m·K. This is very high thermal conductivity. The diamond film was processed as follows without being separated from the Si substrate. The Si substrate coated with the diamond film was cut into a 0.75 mm × 1.5 mm square shape with a YAG laser. The whole surfaces (the upper face, the lower face, and the side faces) were metallized with Ti, Pt, and Au. A semiconductor laser chip formed of In-Ga-As-P with a dimension of 0.3 mm × 0.6 mm × 0.1 mm was brazed to the substrate coated with the diamond film, which had been metallized, at a temperature of 290°C using a Au-Sn alloy brazing filler metal. In order to find out the optimum condition, the thickness of the brazing filler metal was changed variously. In this example, the heat sink has a larger size since the semiconductor laser has a larger size.

[0051]

Thus, semiconductor lasers each having a heat sink (Si single crystal + 8- m diamond film) were produced. Since the semiconductor lasers were excellent in heat dissipation, the output power of the semiconductor lasers was set to 500 mW this time. Under this condition, each semiconductor laser was allowed to oscillate and thereby the thermal stress was measured. The results are shown in Table 6.

[0052]

[Table 6]

Thermal stress and oscillation performance of lasers each of which was brazed to a heat sink including a single crystal Si substrate coated with a 8- m thick diamond film and was allowed to oscillate continuously at an output power of 500 mW.

Sample No.	26	27	28	29	30
Substrate	Si	Si	Si	Si	Si
Diamond	8	8	8	8	8

Thickness (m)					
Brazing Filler Metal Thickness (m)	1	3	5	7	8
Thermal Stress (MP)	-	60	40	35	20
Laser Oscillation Performance	Element Damaged	Stable Oscillation	Stable Oscillation	Stable Oscillation	Stable Oscillation

[0053]

Sample 26 had the thinnest brazing filler metal and the semiconductor laser chip of Sample 26 was cracked during the temperature decrease from the brazing temperature to room temperature. In Samples 27 to 30 with the brazing filler metals having thicknesses of 3 m to 8 m, laser oscillation was stable. The diamond film had a thickness of 8 m and the heat dissipation was superior to any of those in the above-mentioned examples. Hence, this is the most preferable example.

[0054]

[Effect of the Invention]

A semiconductor laser according to the present invention includes a heat dissipation part formed of a vapor synthetic diamond with a thickness of 3 m to 9 m synthesized on a plate-like base which is joined to a semiconductor laser chip with a brazing filler metal layer having a thickness of 2 m to 8 m. Hence, the semiconductor laser element is not damaged by thermal stress and allows stable laser oscillation at high output power. The semiconductor laser element is ideal as a high output semiconductor laser for long-distance backbone transmission.

[Brief Description of the Drawings]

[FIG. 1] FIG. 1 is a cross-sectional view showing a configuration of a semiconductor laser of the present invention.

[Description of Reference Numerals]

1 semiconductor laser chip
2 brazing filler metal layer
3 metallized layer
4 vapor synthetic diamond layer
5 substrate

FIG. 1

1	SEMICONDUCTOR LASER CHIP
2	BRAZING FILLER METAL LAYER
3	METALLIZED LAYER
4	VAPOR SYNTHETIC DIAMOND LAYER
5	SUBSTRATE